METHOD, APPARATUS, COMPUTER PROGRAM AND STORAGE MEDIUM FOR RECORDING A MOVEMENT OF A USER UNIT

Cross-reference to Related Applications

The present application claims the benefit of Swedish patent application No. 0303370-1 and U.S. provisional patent application No. 60/529627, both of

5   which were filed on December 16, 2003, and both of which are hereby incorporated by reference.

Field of the invention

The present invention generally relates to recording of a movement and, more specifically, to a method for

10 recording a movement of a user unit over a base, which is provided with a position code. The recording of the movement may e.g. be carried out in order to electron-ically record handwritten information.

The invention also relates to an apparatus, a

15 computer program and a storage medium which can be used for recording a movement.

Background Art

It is known to digitize handwriting by determining the movement of a pen that is used for providing the

20 handwriting. The movement may e.g. be determined by one or more accelerometers mounted to the pen. Another alternative is to use a base with a position code and to provide the pen with a sensor which records the position code locally at the tip of the pen during the pen's

25 movement over the base. A processing unit, arranged in the pen or externally thereof, can then decode the position code to a series of position indications, e.g. coordinates, which reflects the pen's movement over the base.

30   WO 01/26033, US 5,477,012, WO 00/73983 and WO 92/17859 disclose different examples of position codes that could be used for recording handwriting.

Moreover, WO 01/75779 discloses a form provided with a position code enabling digital recording of information

written on the form. In addition to the position code,
the base is here provided with a form layout, such as
frames around entry fields and text indicating what
information should be filled-in in the entry fields.

5   According to WO 01/75779, the form layout can be
printed on the base simultaneously with the position code
or in different runs. In order not to disturb the reading
of the position code, different printing inks should be
used for the form layout and the position code. The
10   printing ink for the form layout should moreover be
invisible for the sensor in the pen. If both the printing
code and the form layout are printed with the same
printing ink, the form layout may partly obscure the
printing code, making it impossible to decode the
15   position code in areas close to the form layout or in
areas obscured by the form layout.

However, the use of different printing inks is
unpractical. It would be more practical if the pen could
be used on forms printed on blank papers by means of a
20   monochrome printer, e.g. a monochrome laser printer.

Summary of the invention

One object of the invention is to make possible the
determination of a movement of a user unit over a base
which is provided with a position code when the position
25   code is insufficiently recorded, e.g. because the
position code is wholly or partly obscured by other
graphics.

Another object of the invention is to make possible
the determination of a movement of a user unit over a
30   base that is provided with a position code and other
graphics printed with the same printing ink.

One or more of these objects are at least partly
achieved by a method, an apparatus, a computer program
and a storage medium according to the independent claims.

35   According to a first aspect, the invention is a
method of recording a movement of a user unit over a
base, which is provided with a position code, comprising

determining an absolute position of the user unit on the
basis of the position code in at least one image in a
sequence of images of the position code obtained during
the movement of the user unit over the base; determining
5   a spatial relationship between a first and a second image
in the sequence; and determining another absolute
position of the user unit on the basis of the first-
mentioned spatial relationship between the first image
and the second image.
10   The position code need thus not be decodeable in all
the images in the recorded sequence in order to determine
the movement of the user unit. If an absolute position of
the user unit cannot be determined for a specific image,
the user unit's position can as an alternative be
15   determined based on the spatial relationship between two
images in the sequence and a previously or later
determined absolute position.
         The steps of determining an absolute position of the
user unit on the basis of the position code in at least
20   one image and of determining av spatial relationship
between a first image and a second image may thus be
carried out in arbitrary order.
         The first or second image may be the same image as
the one for which the first mentioned-absolute position
25   of the user unit is determined.
         The second or the first image may be the same image
as the one for which the other absolute position of the
user unit is determined.
         The first-mentioned absolute position of the user
30   unit may be determined by decoding the position code in
the image. Other methods may also be used as will appear
from the following description.
         When determining the first-mentioned absolute
position of the user unit, the position code in two or
35   more images can be used if the position code in one of
the images is insufficient for enabling the decoding of
an absolute position.

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     As is evident from above, the images are not always
processed one by one to determine positions of the user
unit, but at times a position is determined based on
information from several images. The use of more than one
5   image for decoding a position is here referred to as a
distributed decoding.
     Thus, the method could also be described as a method
of recording a movement of a user unit over a base, which
is provided with a position code, which method comprises
10   recording a sequence of images, each of which corresponds
to a partial area of the position code which is
sufficiently large for allowing least one position to be
decoded, and using information from more than one image
for determining a user unit position.
15   The invention can be used in all situations where
the position code of an image cannot be decoded for one
or another reason. The reason for the inability to decode
the position code need thus not be that the position code
is partly obscured by other graphical information. The
20   invention can also be used for instance when the position
code is deformed or otherwise incorrect on the base so
that decoding of an absolute position is impossible or
when the position code is absent locally on the base.
     If desired, the invention can of course also be used
25   when the position code in every image is decodeable to an
absolute image. There may e.g. be situations where the
distributed decoding is faster and/or easier and/or more
secure to carry out compared to the decoding of the
position code in every image.
30   An absolute position should in this application be
interpreted as a position defined without reference to
other positions, e.g. a position defined by one or more
absolute coordinates.
     The first and second images may be any pair of
35   images in the sequence. The first image may be located
before or after the second image in the sequence. The
sequence may include only images with overlapping

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contents, or some images with overlapping contents and
some without, or only images without overlapping
contents. The images of the sequence may have been
recorded without the user unit having been lifted from
5   the base during the recording. The user unit may also
have been lifted from the base at one or more occasion
during the recording and then put down on the base again.

The position code may define positions in one or
more dimensions. The movement that is recorded may be a
10 movement in one or more dimensions.

The determining of the spatial relationship may
comprise determining the best overlap position between
the first and second images. One way of doing this is to
correlate content of at least the first and second
15 images. The first and second images can be partly over-
lapping. In this case at least part of the content of
these images can be directly compared in order to estab-
lish their spatial relationship. They may, but need not,
be successive images in the sequence.

20   Alternatively, the images are not overlapping, but
they belong to a series of partly overlapping images so
that their spatial relationship can be established by
succesively determining the spatial relationship with
intervening images in the sequence.

25   As yet another alternative, the first and second
images do not have overlapping contents but the content
is such that the spatial relationship can nevertheless be
determined based on the contents of the images.

The images can be correlated in preprocessed or
30 unpreprocessed format. The images can be e.g. binarized,
in gray scale or in colour.

The correlation can be made on a pixel-level or on a
higher level, e.g. on a feature level, where specific
features in the images are compared. Each feature can be
35 represented by a number of pixels. It can have a specific
form. Part of a form layout or other graphical informa-
tion on the base can be used as features. Handwriting

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made by ink from a user unit can also be used for feature
correlation.

A position code usually consists of a plurality of
symbols or marks, where each symbol codes a value, e.g. a
5   binary value. The spatial relationship between two images
can therefore also be determined based on the correlation
of symbol values or values determined for groups of
symbols.

The spatial relationship can e.g. be expressed or
10 stored as a vector indicating the offset between the
first and second images in one or two or more dimensions.

According to a second aspect, the invention concerns
an apparatus which comprises a control unit, which is
adapted to perform a method according to the first
15 aspect.

The processing unit may e.g. be realized by a suit-
ably programmed processor, by specifically adapted hard-
ware, such as an ASIC (Application-Specific Integrated
Circuit) or an FPGA (Field Programmable Gate Array), by
20 digital or analog circuits or any combination thereof.
The processing unit can reside in the same unit as the
sensor that images the position code or in another unit.

According to a third aspect the invention concerns a
computer program, which comprises program code that, when
25 executed in a computer, causes the computer to carry out
a method according to the first aspect.

The computer program can be stored on and distribut-
ed in the form of a storage medium, such as an electronic
memory like RAM, SRAM, DRAM, SDRAM, ROM, PROM, EPROM,
30 EEPROM, etc; an optical disk; a magnetic disk or tape; or
some other commercially available storage medium. The
storage medium can also be a propagating signal.

Other objects, features and advantages of the inven-
tion are apparent from the following detailed description
35 of the invention, from the appended claims and from the
drawings.

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Of course, features of the different embodiments of the invention may be combined in one and the same embodiment.

Generally, all terms used in the claims are to be
5   interpreted according to their ordinary meaning in the technical field, unless explicitly defined otherwise herein. All references to "a/an/the [element, device, component, means, step, etc]" are to be interpreted openly as referring to at least one instance of said
10 element, device, component, means, step, etc., unless explicitly stated otherwise. The steps of any method disclosed herein do not have to be performed in the exact order disclosed, unless explicitly stated otherwise.

Brief Description of the Drawings

15   The invention will now be described in more detail with reference to the accompanying drawings.

Fig. 1 is a schematic view of a system in which distributed decoding can be used.

Fig. 2 is a schematic illustration of how a sequence
20 of images is recorded from a base with a position code.

Fig. 3 shows four ideal locations of a mark in a position code.

Fig. 4 is a schematic illustration of a position code which may be used for recording a movement of a user
25 unit.

Fig. 5 is a schematic illustration of a user unit, in which the distributed decoding may be carried out.

Fig. 6 is a schematic block diagram of an electronic circuitry part and an image sensor in the user unit shown
30 in Fig. 5.

Figs 7A and 7B show two images of a form with a form layout that partially obscures the position code.

Figs 8A and 8B show the images of Figs 7A and 7B after preprocessing which includes binarization.

35   Figs 9A and 9B show the images of Figs 8A and 8B after dot localization, raster fitting and perspective correction.

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Figs 10A and 10B show two dot value matrices generated from the images of Figs 9A and 9B.

Fig. 11 is a flow chart illustrating an example of an overall decoding process.

5   Fig. 12 is a flowchart illustrating how the distributed decoding according to the invention may be realized.

Fig. 13 is a diagram which shows the result of the correlation of the dot value matrices of Figs 10A and
10   10B.

Detailed Description of Examples of the Invention

Fig. 1 shows a system for information management, in which the present invention can be used. The system comprises a base 1 in the form of a sheet of paper, an appa-
15   ratus for recording a movement in the form of a pen-style user unit 2, and an external unit 3. The sheet of paper constitutes a form. The entire sheet of paper may be provided with a position code 4, only a small part of which is schematically indicated in an enlarged scale,
20   and a form layout 5, which here comprises text 6, boxes 7 to be filled-in and images 8. In this example, it is assumed that the position code and the form layout 5 are printed with the same printing ink or with different printing inks which are however both visible for the user
25   unit. This may result in that the position code cannot be recorded in areas where it is obscured by the form layout.

The user unit 2 can be used to write on the sheet of paper 1 in the same way as with an ordinary pen and to
30   simultaneously record what is being written in digital form by recording of its movement. To this end, the user unit 2 continuously during writing records images of the position code at the tip of the user unit 2. If the position code in each image is decoded to an absolute
35   position, the resulting sequence of such decoded positions usually constitutes an accurate digital representation of the movement of the user unit 2 over

the base and, thus of what is written on the base 1 and
where.

The position decoding is carried out in the user
unit 2 and/or the external unit 3, to which the recorded
5   images can be sent automatically (on-line) or when
commanded by the user. The external unit 3 may be a PC, a
mobile phone, a PDA (Personal Digital Assistant), a
server on the Internet or any other unit that has the
capacity to carry out the position decoding. For the
10 digitally recorded information to correctly reflect the
user unit's movement over the sheet of paper, it is im-
portant that the position decoding be made as correctly
and completely as possible.

The position code 4, which will be described in more
15 detail below, is made up of symbols or marks, which are
arranged or designed according to predetermined rules. If
a partial area of the position code is correctly imaged,
said partial area having a predetermined minimum size,
the position of the partial area in the total position
20 code can be determined unambiguously by means of one or
more symbols in the imaged partial area and a predeter-
mined decoding algorithm. The position can be obtained
as a pair of coordinates in a Cartesian or another coor-
dinate system.

25   The decoding may function well as long as the
position code in the partial area is completely and
correctly imaged. Under actual conditions, however, the
user unit 2 sometimes cannot image the position code
entirely correctly, for instance because of poor lighting
30 conditions, or because of defects in the imaging system.
Problems can also arise if the position code is not quite
accurately reproduced on the base but has been deformed
to some extent when being applied to the base.

If the position code contains redundant information,
35 errors affecting a limited number of symbols can under
certain conditions be corrected.

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Furthermore, WO 03/038741, discloses a method for
position decoding, where, in case of a decoding error,
information determined from the partial area is compared
or matched with information about how the position code
5   is composed in a matching area close to a previously
successfully decoded position. The best matching portion
of the known matching area is selected, and a correspon-
ding position is determined as the decoded position.

If, however, too large parts of the position code
10   are deformed or missing, for instance because the
position code is partly or totally obscured by a form
layout printed with the same kind of printing ink as the
position code, error correction or matching against the
known composition of the position code will not be
15   possible because too many symbols are missing or
incorrect. Instead a distributed decoding may be used as
explained in the following with reference to Fig. 2.

Fig. 2 schematically shows a small part of the base
1 of Fig. 1 but for the sake of clarity neither the
20   position code, nor the form layout is shown on the base.
When a pen stroke is made on the base, the user unit 2
simultaneously records images of the base locally at the
tip of the user unit. Fig. 2 schematically shows an
example of the positions in which four such images A-D
25   are recorded. The images here form a sequence of part-
ially overlapping images. Ideally, in this example, the
position code of each image is decoded to an absolute
position indication, e.g. in the form of a pair of
coordinates. However, if the position code is obscured
30   this may not be possible. Assume e.g. that no absolute
position can be decoded from the position code in image
A. Then information from image A is saved. If no position
can be determined for image B either, the best overlap
position between images A and B is determined. Then it is
35   checked whether the position code in image A and the
position code in image B together can be decoded to an
absolute position. Even if the position code in image A

and image B taken alone cannot be decoded because it is
obscured to a too large extent in the respective image,
the combined position code from both images may be
decodable to an absolute position. This is schematically
5   illustrated in Fig. 2, with a hatched area H covering
part of images A and B. If so, the user unit's absolute
positions when recording image A and image B can be
determined, since the spatial relationship between the
two has been established.

10   If an absolute position cannot be decoded from the
combination of images A and B, the spatial relationship
between these images is saved, e.g. as a vector V ref-
lecting the offset in two dimensions, e.g. the horizontal
and vertical directions, between images A and B. The
15   above procedure is repeated until an image or combination
of images is found in which the position code is
sufficiently completely and correctly imaged for an
absolute position to be decoded. Assume e.g. that an
absolute position can be decoded from the position code
20   in image C. If the offset between images B and C is also
determined, then the absolute positions of images A and B
can be determined by successively subtracting the offset
from the absolute position of the subsequent image in the
sequence. If again an absolute position cannot be decoded
25   from the position code in image D, the offset between
images C and D is determined and the absolute position of
image D determined by adding the offset to the absolute
position decoded from the position code in image C.
         Before explaining the distributed decoding in
30   further detail, the position code and the user unit used
in this example will be described in somewhat more detail
with reference to Figs 3 and 4, and Figs 5 and 6,
respectively. A still more comprehensive description of
the position code could be found in WO 03/001440.
35   The position code is based on a number sequence
which below is referred to as a difference number
sequence. This difference number sequence has the prop-

erty that if one takes an arbitrary partial sequence of a
predetermined length, for instance a partial sequence
with five difference numbers, this partial sequence
always has an unambiguously determined location in the
5   difference number sequence. In other words, it appears
only once in the difference number sequence and can thus
be used for position determination. A sequence having
this property is sometimes called a DeBruijn sequence.
More specifically, the difference number sequence "runs"
10 along the x axis as well as along the y axis of the
position code.

The actual position code is made up of simple gra-
phical symbols or marks 22 which can assume four diffe-
rent values, 0-3, depending on their respective position
15 in relation to a nominal position 23 or raster point. As
seen in Fig. 3, each symbol 22 has the shape of a dot and
is displaced a distance 24 in one of four different di-
rections relative to the nominal position 23. The nominal
position 23 is at an intersection between raster lines 21
20 in a visible or invisible or virtual raster or grid. The
value of the symbol is determined by the direction of the
displacement. Each symbol value 0-3 can be converted into
one bit which is used for coding an x coordinate and one
bit which is used for coding a y coordinate, i.e. into
25 the pairs of bits (0,0), (0,1), (1,0), and (1,1). Thus,
the coding is made separately in the x direction and the
y direction, but the graphical coding is made with a
symbol which is common to the x and y bits.

It should be mentioned that the coding may for
30 instance be as follow:

Displacement	Bit pair (x,y)
Right	0,1
Up	0,0
Left	1,0
Down	1,1

The distance 24 is suitably not less than about 1/8
and not more than about 1/4, preferably about 1/6, of the
5 distance between two adjacent raster lines 21. The dist-
ance can, for example, be about 300 micrometers or about
254 micrometers. The latter distance is particularly
suitable for printers and scanners, which often have a
resolution that is a multiple of 100 dpi (dots per inch).
10 All the symbols of the position code are usually printed
with one and the same printing ink so that the position
code is monochrome.

Each position is coded by 6 * 6 symbols which can
thus be converted into a 6 * 6 bit matrix for an x coor-
15 dinate and a 6 * 6 bit matrix for a y coordinate for the
position. If the x bit matrix is considered, this can be
divided into six columns of six bits each. Each sequence
of bits in a column constitutes a partial sequence in a
63-bit-long cyclic main number sequence which has the
20 property that if a partial sequence having a length of
six bits is selected, this has an unambiguously deter-
mined place in the main number sequence. The six columns
can thus be converted into six position numbers or
sequence values which correspond to six places in the
25 main number sequence. Between these six position numbers,
five difference numbers can be formed in neighboring
pairs, which constitute a partial sequence of the
difference number sequence and which thus have an
unambiguously determined place in the same and,
30 consequently, an unambiguously determined place along the
x axis. For a certain x coordinate, the position numbers
will vary depending on the y coordinate. On the other

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hand, the difference numbers will be the same
independently of the y coordinate, since the position
numbers always vary according to the main number
sequence, which is repeated cyclically in the columns in
5   the entire position-coding pattern.

Correspondingly, six rows in the y bit matrix define
six position numbers in the main number sequence. These
six position numbers define five difference numbers,
which constitute a partial sequence of the difference
10 number sequence and which thus have an unambiguously
determined place along the y axis.

Fig. 4 shows a very small part of the position code
with 4*4 symbols. The raster lines 21 are shown in the
figure for illustration purposes only. In general, the
15 raster is virtual.

When the position code is used, images of different
parts of the position code are recorded, as has been des-
cribed above. The images may contain considerably more
than 6 * 6 symbols. Thus the position code may be decoded
20 based on different sets of 6 * 6 symbols if a larger
number of symbols are visible in the image. Surrounding
symbols may also be used in the decoding, inter alia, for
error detection and/or correction. The position code is
of a so called "floating type". It means that any
25 arbitrary partial area comprising a predetermined number
of symbols, here 6*6 symbols, will define a position and
that at least some of the symbols in the arbitrary par-
tial area contribute to the coding of more than one posi-
tion. Otherwise stated, if the arbitrary partial area is
30 moved a symbol distance up, down, to the left or to the
right, a new position will be defined by the symbols in
the arbitrary partial area thus moved.

In the following, an example of how the user unit 2
of Fig. 1 may be realized will be described with refer-
35 ence to Figs 5 and 6. In this example, the user unit 2
comprises a casing or shell 2011 having approximately the
same shape as a pen. In one short side of the casing

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there is an opening or window 2012 through which images
are recorded.

The casing essentially contains a camera system, an
electronic system, and a power supply.

5   The camera system 2014 comprises at least one illu-
minating light source, a lens and/or mirror arrangement
and an optical image reader or image sensor (not shown in
the Figure). The light source, suitably a light-emitting
diode or a laser diode, illuminates a part of the area

10 that can be viewed through the window 2012, by means of
infrared radiation. An image of the viewed area is
projected on the image sensor by means of the lens
arrangement. The image sensor may be a light-sensitive
area sensor, such as a CCD (Charge Coupled Device) or

15 CMOS (Complementary Metal-Oxide Semiconductor) sensor,
which may be triggered to record two-dimensional images
at a fixed rate, typically of about 70-100 Hz. The sensor
may be sensitive to infrared light. The sensor and the
illuminating light source may be triggered in a

20 synchronized fashion.

Generally speaking, the image sensor may be replaced
by any kind of sensor that is suitable for imaging the
position code so that an image of the symbols is obtained
in black and white, in grey scale or in color. Such a

25 sensor can be a solid-state single- or multi-chip device
which is sensitive to electromagnetic radiation in any
suitable wavelength range. For example, the sensor may
include a CCD element, a CMOS element, or a CID element
(Charge Injection Device). Alternatively, the sensor may

30 include a magnetic sensor array for detection of a
magnetic property of the marks. Still further, the sensor
may be designed to form an image of any chemical,
acoustic, magnetic, capacitive or inductive property of
the marks.

35   The power supply to the user unit may be a battery
2015. The power supply may as an alternative or as a

supplement be obtained via a cable from an external power
source (not shown).

 The electronic system comprises a control unit 2016
and a memory block 2013, to which the control unit is
5 connected. The control unit is responsible for the
different functions in the user unit, e.g. forthe reading
of images from the sensor and the carrying out of
position decoding on the basis of these images. The
control unit 2016 may be implemented by a commercially
10 available microprocessor such as a CPU ("Central
Processing Unit"), by a DSP ("Digital Signal Processor")
or by some other programmable logical device, such as an
FPGA ("Field Programmable Gate Array") or alternatively
an ASIC ("Application-Specific Integrated Circuit"),
15 discrete analog and digital components, or some combi-
nation of the above. The memory block 2013 comprises
preferably different types of memory, such as a working
memory (e.g. a RAM) and a program code and persistent
storage memory (a non-volatile memory, e.g. flash
20 memory). Associated software is stored in the memory
block 2013 and is executed by the control unit 2016 in
order to provide a user unit control system for the
operation of the user unit.

 The casing 2011 also carries a pen point 2017 which
25 allows the user to write or draw physically on a surface
by an ordinary pigment-based marking ink being deposited
thereon. The marking ink in the pen point 2017 is suit-
ably transparent to the illuminating radiation in order
to avoid interference with the opto-electronic detection
30 in the user unit. A contact sensor 2021 is operatively
connected to the pen point 2017 to detect when the pen is
applied to (pen down) and/or lifted from (pen up), and
optionally to allow for determination of the application
force. Based on the output of the contact sensor 2017,
35 the camera system 2014 is controlled to capture images
between a pen down and a pen up. The resulting sequence

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of temporally coherent positions forms an electronic
representation of a pen stroke.

The pen point 2017 can be extendable and retract-
able, so that the user can control whether or not it is
5   to be used. In certain applications, the user unit need
not have a pen point at all.

The electronics system further comprises a communi-
cations interface 2019 for exposing data to a nearby or
remote apparatus such as a computer, mobile telephone,
10   PDA, network server, etc. The communications interface
2019 may thus provide components for wired or wireless
short-range communication (e.g. USB, RS232, radio trans-
mission, infrared transmission, ultrasound transmission,
inductive coupling, etc), and/or components for wired or
15   wireless remote communication, typically via a computer,
telephone or satellite communications network.

The pen may also include an MMI 2020 (Man Machine
Interface) which is selectively activated for user
feedback. The MMI may include a display, an indicator
20   lamp or LED, a vibrator, a speaker, etc.

Still further, the pen may include one or more
buttons 2018 by means of which it can be activated and/or
controlled.

The user unit can be divided into different physical
25   casings. The sensor and other components that are neces-
sary for capturing images of the position code and for
transmitting them may be located in a first casing, while
the components that are necessary for carrying out the
position decoding may be located in a second casing.

30   Fig. 6 is a schematic block diagram of an example of
an implementation of the control unit 2016, the memory
block 2013 and the image sensor in the user unit shown in
Fig. 5. An ASIC 700 contains a CPU 720 as a main
controller of the electronic circuitry. The CPU 720 has
35   access to a memory 730 through an on-chip data bus 760.
The image sensor is implemented as a CMOS area sensor
750, which is connected to the data bus 760 of ASIC 700

and which is capable of producing 96x96-bit, 256-level
grayscale digital images at a frequency of 100 Hz. An
image preprocessor 710 on ASIC 700 will preprocess images
received from the image sensor 750 and may store the

5   preprocessed images in memory 730 before decoding. The
CPU 720 will perform the decoding of the position code in
the preprocessed images into positions. A matching unit
740 may assist the CPU 720 in determining the spatial
relationship between recorded images and/or in matching

10 position code information in an image with previously
known information about the position code in a limited
region.

    In the following, the decoding process will be
explained more in detail with reference to Figs 7-13.

15   Figs 7-10 schematically and for illustration
purposes only show how a pair of images may be processed.
It should be understood that the images are normally
processed substantially in sequence as is evident from
the flowcharts of Figs 11 and 12.

20   During the writing by the user unit 2 on the base 1
in Fig 1, the image sensor 2014 of user unit 2 captures
images of the base, step 1110 in fig 11. The size of each
captured image is at least the same as the partial area
required for determining a position, but usually larger.

25   Figs 7A and 7B show two exemplary images captured in
succession from a base having a position code with a
plurality of dots and a form layout, which form layout in
these images includes letters or parts thereof. It is
evident that the images have overlapping contents and

30 that the images are obtained as grayscale images.

    Each captured image is preprocessed, step 1120, so
as to form a suitable input for a following step 1130, in
which the dots are localized, the virtual raster fit to
the dots and the perspective corrected. In this

35 connection, the perspective-corrected raster with the
dots may be displaced so that a raster point is localized
in the origin of the sensor coordinate system.

Steps 1120 and 1130 may be performed by way of tech-
niques that are well known in the art, such as filtering,
binarization or thresholding, and utilization of Fourier
transforms. The raster may for instance be determined as
5   described in WO 01/26034, WO01/75783 or WO 03/049023.

Figs 8A and 8B show the images of Figs 7A and 7B
after preprocessing. The images are now in binary form.
It is evident that the position code is missing in those
parts of the images that correspond to the form layout in
10   Figs 7A and 7B. The binarized images also comprise pixel
formations that evidently do not pertain to the position
code.

Figs 9A and 9B show the images of Figs 7A and 7B
after step 1130, i.e. after the dots 22 have been local-
15   ized and the virtual raster 21 fit thereto. Also, the
perspective has been corrected so that the raster 21 is a
square raster.

It should be mentioned that the perspective need not
necessarily be corrected. The dot values can also be
20   decoded from images with a non-corrected perspective, but
by taking the perspective information into account. It is
believed that the result will be better if the perspec-
tive is corrected and the dot values decoded from the
perspective-corrected dot matrix.

25   The intersections of the raster lines constitute
nominal positions 23 for the dots. If the position code
is complete and correctly imaged, each nominal position
23 should have one associated dot, which is displaced in
one of four directions from the nominal position 23
30   depending on which value it codes. In Figs 9A and 9B,
some of the nominal positions 23 lack however an associ-
ated dot and other nominal positions have more than one
associated dot. This may e.g. be due to obscuring form
layout, imperfect imaging, imperfect preprocessing and/or
35   imperfect dot localization.

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In the following step 1140 a dot value is determined
for each nominal point 23. Various methods can be used
for this purpose.

For instance, if a nominal point 23 has only one
5   associated dot, it may be investigated whether it lies
within a certain "safe" zone around any of the four ideal
displacement positions shown in Fig. 3. Such "safe" zones
may e.g. be defined by circular areas having their
centers at respective one of the four ideal displacement
10   positions and having a predefined radius. Thus, if a dot
is found to lie within any such "safe" zone, the dot is
held to have the value represented by the ideal displace-
ment position that forms the center of the "safe" zone.

If no dot value can be determined for a nominal
15   point because e.g. there is no dot associated with the
point or because two dots are placed equally far from the
ideal placement, the position is marked by a "-".

Alternatively, for each nominal position the proba-
bility that the associated dot(s) assume any of the four
20   different possible dot values may be determined, e.g. as
described in WO 03/001441. Then, probability threshold
values may be applied, such that if a certain dot encodes
any of the dot values 0-3 at a probability in excess of
e.g. 0.8, where 0.8 is the threshold, then the dot is
25   assigned that dot value, otherwise "-".

The determination of the dot values of the dots in
Figs 9A and 9B results in the dot value matrices shown in
Figs 10A and 10B, where 0-3 represent the dot values and
"-" indicates that no dot value could be determined for
30   the corresponding nominal position.

Each one of the dot value matrices of Figs 10A and
10B can also be separated into two bit matrices – one x
matrix and one y matrix – by translating the dot values
0-3 to bit pairs 0,0; 0,1; 1,0; and 1,1, where the first
35   bit is used in the x matrix for determination of an x
coordinate and the second bit is used in the y matrix for

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determination of a y coordinate as described for instance
in WO 01/26033.

     Finally, the actual decoding of the dot value
matrices in Figs 10A and 10B to absolute positions is
5   carried out in step 1150. One way of carrying out this
step will be described more in detail with reference to
the flow chart in Fig. 12.

     First, in step 1200, a New Image is retrieved for
the decoding of the position information. The New Image
10   is a captured image that has been processed as described
above so that two bit matrices have been obtained. To
simplify the description, these two matrices are however
referred to as the New Image. In step 1205, it is deter-
mined whether it is possible to decode the position code
15   in the New Image to an absolute position. If the position
code is insufficiently recorded, for instance because it
is partly or wholly obscured on the base, the New Image
may not include sufficient information for allowing an
absolute position to be decoded.

20   If the position code cannot be decoded, the spatial
relationship or the relative position of the New Image
with regard to a Previous Image is determined, step 1210,
by way of correlation. If there is no Previous Image
because the New Image is the first image, the process
25   simply proceeds to the next step.

     In the following step, step 1215, it is checked
whether an absolute position is known, i.e. has been
determined, for the Previous Image. If so, an absolute
position is determined for the New Image, step 1225,
30   using the relative position determined in step 1210, and
stored as an absolute position of the New Image. If no
absolute position is known, the relative position is just
stored as a relative position of the New Image, step
1220, and the process proceeds to step 1270, where the
35   New Image is set to be the Previous Image. However, if
there is no Previous Image, there is evidently no known
absolute position in step 1225 and no relative position

to be stored in step 1220 and the process thus just
proceeds to step 1270.

After step 1270, the process restarts in step 1200
with a New Image.

5   If, on the other hand, it is determined in step 1205
that the position code is decodable to an absolute posi-
tion, then the decoding is carried out for the New Image
in step 1230. In the following step 1235, it is checked
whether the absolute position is known for the Previous

10   Image, if any.

As is evident from above, the absolute position of
the Previous Image can be known either from a decoding of
the position code in the Previous Image or from a
calculation based on the relative position.

15   If the absolute position is known, the decoded
absolute position is simply stored in step 1240 as an
absolute position of the New Image and the process
proceeds to step 1270, after which it restarts in step
1200.

20   If, in the alternative, the absolute position is
unknown, the New Image is correlated with the Previous
Image, step 1245, in the same way as in step 1210. There-
after, the absolute position for all previous images
without a stored associated absolute position can be

25   calculated using the stored relative position(s), step
1250.

It appears from above that if at the beginning of a
pen stroke, the position code is insufficiently recorded
in a series of images, then finally when an absolute

30   position is decodable, it will be possible to go back-
wards and determining the absolute positions of the
previous images.

Once, however, an absolute position has been deter-
mined for one image, the absolute position of every image

35   with which a spatial relationship is determinable, can
also be determined directly, either by decoding of the

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position code in the image or by comparison of at least
part of its content with that of the previous image.

If an absolute position has been determined for two
images and it has been impossible to determine a position
5   for an image in between, the absolute positions of these
two images can be used for estimating the position of the
image in between, e.g. by interpolation.

The correlation in steps 1210 and 1245 can be
carried out in different ways. One way is to correlate
10 dot values of the dot value matrices or binary values of
the x and/or y bit matrices by checking in which overlap
position the highest number of dot values/binary values
correspond. An advantage of this alternative is that the
Previous Image could be stored in a relatively compact
15 manner.

Another alternative would be to carry out the
correlation on a still higher level. As previously
explained, each sequence of bits in a column in a partial
area of 6*6 symbols constitutes a partial sequence in a
20 63-bit-long cyclic main number sequence which has the
property that if a partial sequence having a length of
six bits is selected, this has an unambiguously deter-
mined place in the main number sequence. The six columns
can thus be converted into six position numbers or
25 sequence values which correspond to six places in the
main number sequence. Thus, those columns in the x matrix
that are sufficiently complete can be decoded to sequence
values and the correlation can be carried out based on
the sequence values. In the corresponding way, rows in
30 the y matrix can be decoded to sequence values and
correlation performed using these sequence values.
Evidently, other groups of symbols, which could be
decoded to a group symbol value could also be used for
correlation.

35   A further alternative would be to correlate the
Previous Image and the New Image in the preprocessed and
binarised form, but before conversion to a dot value

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matrix or to binary value matrices. This comparison could
be carried out in a well-known way by calculating a score
based on the number of overlapping pixels in different
overlap positions. Examples of methods that can be used
5   for pixel-wise correlation are disclosed in e.g.
WO 98/20446 and WO 99/36879.

       Yet another alternative would be to correlate the
images as they appear before preprocessing, e.g. in
grayscale form.

10   Still another alternative would be to correlate the
images using distinct features in the images, for
instance the form layout in Figs 7A and 7B.

       Suitable correlation techniques for grayscale and
feature correlation are well-known to the skilled person
15   and include e.g. Sum of Square Errors and Sum of Absolute
Differences.

       If the user unit comprises a pen point which outputs
writing ink that is visible to the image sensor of the
user unit, correlation can be carried out on the basis of
20   handwriting that appears in the images.

       If the Previous Image and the Next Image are corre-
lated on the basis of the dot values, the following
correlation formula f(u,v) could be used:

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$$f(u,v) = \frac{\sum_{x,y} I(im1(x,y), im2(x+u, y+v))}{(width - |u|)(height - |v|)},$$

       where $I(a,b)$ is the equality function evaluating to
30   1 if $a=b$ and 0 otherwise, $im\ 1$ is the Previous Image,
$im\ 2$ is the New Image, $width$ is the width of the images,
$height$ is the height of the images, u and v are the
elements of the translational vector which indicates the
overlap position, and x and y are pixel coordinates.

35   Fig. 13 is a diagram which shows the result of the
correlation of the dot value matrices in Figs 10A and

10B. In the diagram, u and v are the elements of the
translational vector and z indicates a correlation
measure. The peak in the diagram indicates that the New
Image is translated by a vector (3,0) relative to the
5 Previous Image. However, when the spatial relationship
between the Previous Image and the New Image is deter-
mined, the possible displacement of the perspective-
corrected raster in order to have a raster point in the
origin of the sensor coordinate system may have to be
10 taken into consideration.

The invention has been illustrated above by means of
an example of a specific position code including dots
that are displaced from nominal positions in a raster.

However, the distributed decoding could equally well
15 be applied in connection with other types of position
codes. It could, e.g. be used for position codes which
code each position with a single, more complex symbol,
like the position code in US 5,477,012, for other
position codes which code each position with a plurality
20 of symbols but in a non-floating manner, or for other
position codes of floating type, like WO 00/73983 or for
any other position code.

The invention has furthermore been illustrated with
a sequence of overlapping images. As indicated above, a
25 spatial relationship between two images in a sequence of
images can sometimes be determined even though there is
no overlapping content. Instead the spatial relationship
may be determined on the basis of the contents of the
images. The position code used in the example above is
30 based on cyclical main number series, which are repeated
in columns and rows. If, for instance, the user unit is
moved in the horizontal direction over the position code
and two non-overlapping images are captured, one after
the other, and if the distance between the images is
35 equal to or less than half the length of the cyclical
main number series in any of the two possible directions,
then the spatial relationship can be determined from a

comparison of the contents of the images and from the knowledge about the cyclical main number series. This is of course just but an example.

The decoding example described with reference to the
5   flowchart of Fig. 12 can be expanded. After the corre-
lation step 1210, a check may e.g. be carried out as to whether the combined position codes of the New Image and the Previous Image are decodable to an absolute position. If not, the process continues as shown with step 1215. If
10 however an absolute position can be decoded, the absolute position of the New Image is determined and stored. If no absolute position is known for the Previous Image, its absolute position is also determined and stored. Then the New Image is set to the Previous Image in step 1270.

15   As has been mentioned above, an image may contain several sets of symbols enabling the determination of several different positions. However, the position of an image or of the user unit when the image was recorded is always defined in relation to a specific reference point
20 in the coordinate system of the user unit sensor, e.g. the upper left corner. It should thus be understood that when it is indicated above that an absolute position is stored for an image, it is the absolute position of the reference point that is stored. If the absolute position
25 of another point in the sensor coordinate system has been determined, the absolute position of the reference point can easily be calculated.

In the examples above, information from the Previous and the New Image is used. However, further images in the
30 sequence can be stored and used in combination when carrying out the distributed decoding.

The determination of an absolute position from one or more images, without using any spatial relationship, can be carried out by calculating an absolute position
35 from the decoded values of a set of dots, as is further disclosed in e.g. US 6,674,427 and US 6,667,695, which are hereby incorporated by reference. An absolute

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position may also be determined by predicting, from a
known absolute position of the user unit, the next
position of the user unit and by matching the predicted
position of the user unit with information about how the
5   position code is constructed in the neighborhood of the
predicted position, as is further described in
WO04/097723, which is hereby incorporated by reference.

In the example of Fig.12, the spatial relationship
between a first and second image is determined only if
10 the absolute position of the first image is not known.
However, according to a variant, the spatial relationship
between two successive images is always determined, the
information being used when needed. No specific decision
on whether or not to determine the spatial relationship
15 need to be taken.

A purpose of the distributed decoding is to obtain
one position for each image in the image sequence.
However, there could be images for which no absolute
position can be decoded from the position code and for
20 which no spatial relationship to another image can be
established. For such images a position may instead be
determined e.g. by interpolation or extrapolation. Else
it could be decided not to record any position for such
an image. There could also be other situations where it
25 is decided not to record any position for an image.

Thus a continuous movement of a user unit over a
base is recorded by means of a sequence of images of a
position code on the base. For some of the images the
position code is directly decoded to absolute positions
30 of the user unit, for other images their spatial rela-
tionship to a previous or subsequent image is determined
and user unit positions determined there from.